Physics 2140 Final Exam Solutions

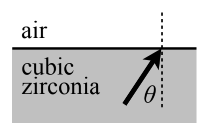
Part 1: New Stuff

1. Cubic zirconia has an index of refraction of $n = 2.15$. The speed of light in vacuum is $c = 3 \times 10^8$ m/s.

[3] (a) **A** How fast does light travel in cubic zirconia?
A) 1.40×10^8 m/s **B)** 2.15×10^8 m/s **C)** 3.00×10^8 m/s **D)** 6.45×10^8 m/s

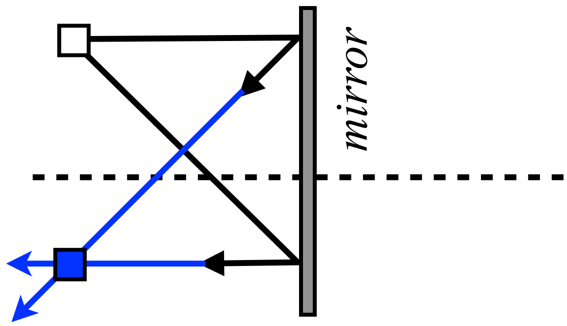
$$v = \frac{c}{n} = \frac{3 \times 10^8}{2.15} = 1.40 \times 10^8 \text{ m/s}$$

[3] (b) What is the maximum angle that a ray of light in zirconia can make with the normal, and still escape into the air without being totally reflected?



$$\theta_c = \sin^{-1}\left(\frac{1}{2.15}\right) = 28^\circ$$

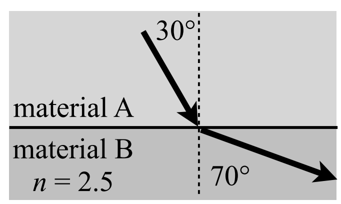
2. The figure shows an object (the square) and a mirror. Two rays are emitted from the square and are reflected by a mirror as shown.



3 (a) **A** What kind of image does the mirror form of the object?
A) real **B)** virtual

3 (b) Draw a box at the location of the image.

3. The figure shows a ray of light moving from material A to material B, as shown. (The horizontal line is the interface, the dashed line is the normal.)



3 (a) **B** In which material does light travel more quickly?
A) Material A **B)** Material B

3 (b) The index of refraction of material B is $n_B = 2.5$. Find the index of refraction of material A.

$$n_A \sin\theta_A = n_B \sin\theta_B$$

$$\implies n_A = n_B \frac{\sin\theta_B}{\sin\theta_A}$$

$$= 2.5 \frac{\sin 70°}{\sin 30°} = \boxed{4.7}$$

3 **4.** **C** A diverging lens always creates an image which is
A) real, and smaller than the object
B) real, and larger than the object
C) virtual, and smaller than the object
D) virtual, and larger than the object

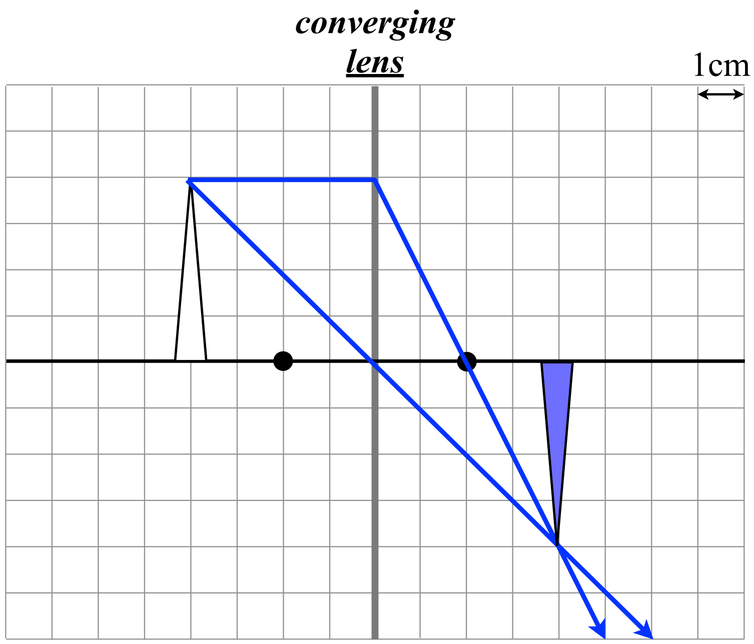
1 **5.** <u>A</u> Compare ultraviolet and infrared light. Which has the larger wavelength?
A) infrared **B)** ultraviolet

1 **6.** <u>B</u> Light of . . . wavelength is *less* likely to be scattered off of dust, but pass through it.
A) shorter **B)** longer

1 **7.** <u>C</u> Light that is reflected from a surface becomes partially
A) diffracted **B)** interfered **C)** polarized **D)** refracted

1 **8.** <u>A</u> We are able to see this painting as a coherent image, and not a bunch of little dots, thanks to
A) diffraction **B)** interference **C)** polarization **D)** refraction

9. The figure shows a triangular object and a converging lens. The squares are 1 cm across.



Use any method you like (equation or ray-tracing) to answer the questions below.

[2] (a) Find $p =$ **4** cm and $f =$ **2** cm .

[2] (b) Find the image location $i =$ **4** cm

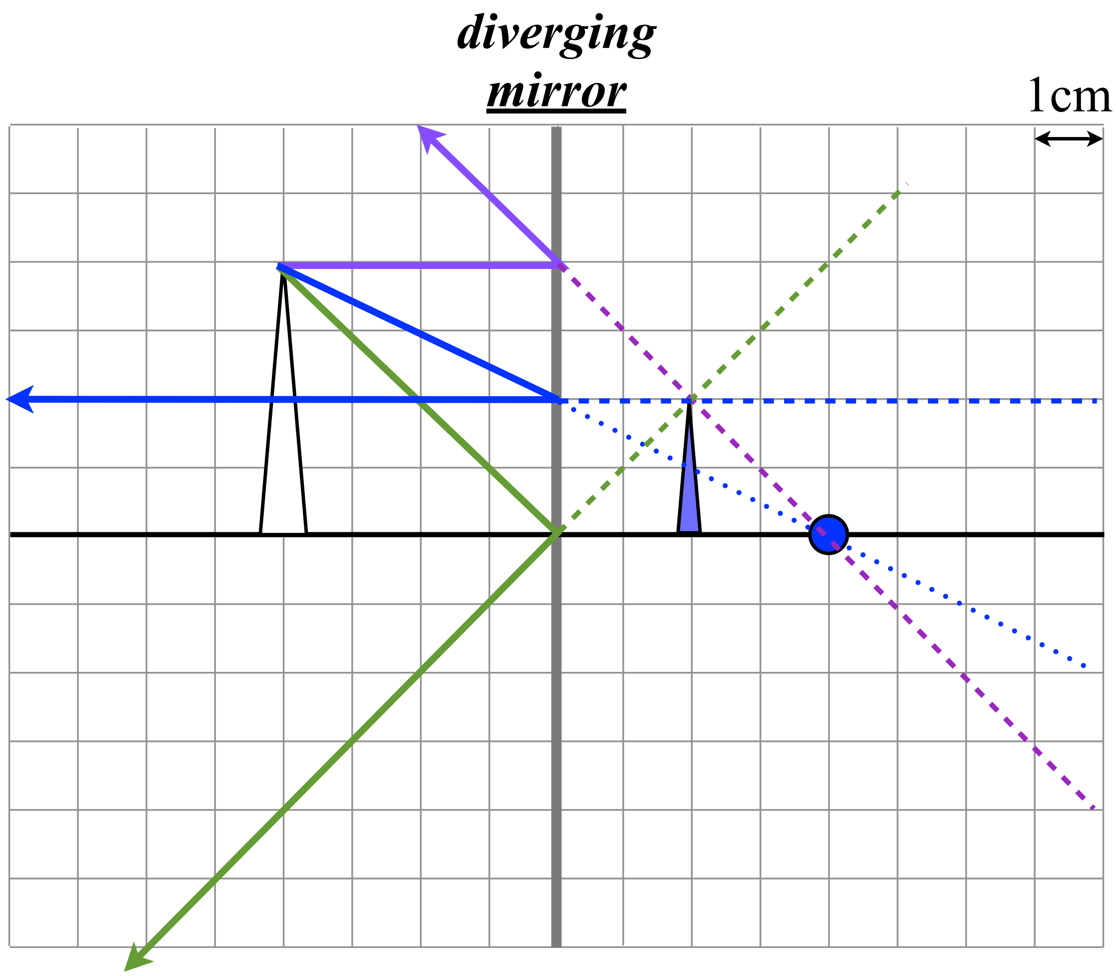
$$i = \frac{pf}{p-f} = \frac{4 \cdot 2}{4-2} = 4\,\text{cm}$$

[2] (c) Find the magnification of the image $M =$ **-1**

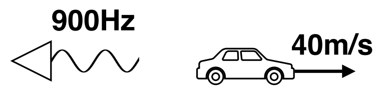
$$M = -\frac{i}{p} = -\frac{4}{4} = -1$$

[2] (d) Draw the image on the diagram.

3 **10.** The figure shows an object and a diverging mirror. The mirror has a focal length of 4 cm. Using ray tracing, find the image created by this mirror. Draw at least two rays from the tip of the object to the tip of the image. (You can use the lens equation to verify your result, but it will not count.)



3 10. A A car is travelling at 40 m/s away from a siren which produces a sound at $f = 900\,\text{Hz}$. What frequency does the driver hear? The speed of sound is 343 m/s.
A) 795 Hz **B)** 806 Hz **C)** 1005 Hz **D)** 1019 Hz

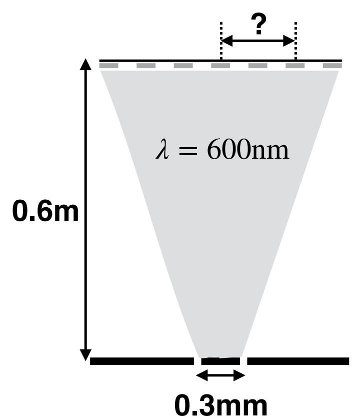


The observer is moving away from the source (which is stationary), so the frequency is smaller than 900 Hz, eliminating C and D. The formula is $f = f_0 \frac{v_w - v_o}{v_w}$ where $v_w = 343\,\text{m/s}$ is the speed of sound, $v_o = 40\,\text{m/s}$ is the speed of the observer, and there's a minus sign on top because they are moving apart. Thus $f = (900\,\text{Hz})\frac{343-40}{343} = 795\,\text{Hz}$

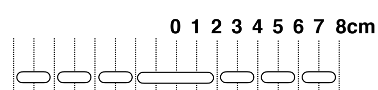
3 11. A Which of these is *not* an electromagnetic wave?
A) gravitational **B)** infrared **C)** yellow light **D)** x-ray

3 12. Laser light with wavelength $\lambda = 600\,\text{nm}$ ($= 600 \times 10^{-9}\,\text{m}$) shines through two thin slits that are $0.3\,\text{mm} = 3 \times 10^{-4}\,\text{m}$ apart, and this creates a pattern on a screen that is 0.6 m. Find the distance marked on the picture.

$$y_2 = \frac{2\lambda L}{d} = \frac{2(600\,\text{nm})(0.6\,\text{m})}{0.3\,\text{mm}} = 2.4\,\text{mm}$$



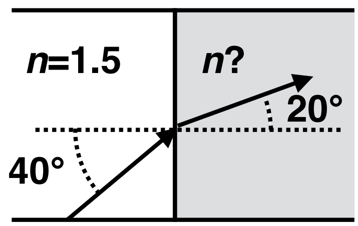
3 13. C The figure shows the pattern created when laser light shines through a single slit. We are given the formula $y_p = \frac{\lambda L p}{a}$ for such occasions. By **looking at the diagram**, which of the following is y_2?
A) 2 cm **B)** 3 cm **C)** 4 cm **D)** 5 cm **E)** 6 cm



y_p is the position of the pth dark spot, so y_2 is the position of the second dark spot from the center, which is at 4 cm.

2 14. **B** …… reflection occurs when light shines on a very flat surface.
A) Diffuse **B)** Specular **C)** Total internal

15. The figure shows light passing from glass ($n_1 = 1.5$) into another material.

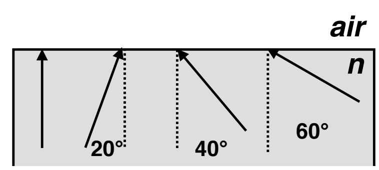


2 (a) **A** In which material is the light moving more quickly?
A) the glass **B)** the other material

3 (b) **E** What is the index of refraction of the other material?
A) 0.8 **B)** 1.0 **C)** 1.2 **D)** 1.8 **E)** 2.8

$n_1 \sin\theta_1 = n_2 \sin\theta_2$, so $1.5 \sin 40^\circ = n \sin 20^\circ \implies n = 1.5\frac{\sin 40^\circ}{\sin 20^\circ} = 2.8$

3 16. The bottom material has index $n = 1.7$ and the top material is air. The critical angle of the material is 36°. Which of these rays **is able to** escape into the air? Place a checkmark next to all that apply.

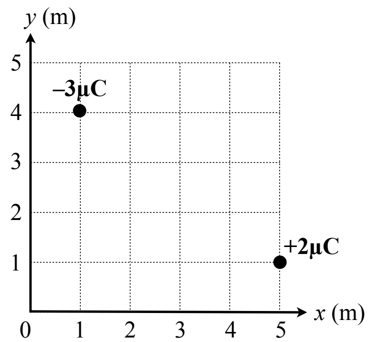


0° ✓ 20° ✓ 40°______ 60°______

The critical angle is the maximum angle at which light can escape in total internal reflection.

Part II: Old Stuff

[3] **11.** Find the force on the positive charge, in component form, due to the negative charge. (For partial credit, tell me what $\vec{d}$ is here.)

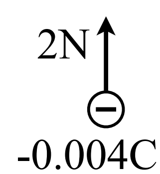


$\vec{d}$ is the vector from source ($-3\,\mu$C) to the target ($+2\,\mu$C), so $\vec{d} = 4\hat{x} - 3\hat{y}$, and $d = \sqrt{4^2 + 3^2} = 5$. Thus

$$\begin{aligned}\vec{F} &= k\frac{q_s q_t}{d^3}\vec{d} \\ &= (9\times10^9)\frac{(-3\times10^{-6})(2\times10^{-6})}{5^3}(4\hat{x} - 3\hat{y}) \\ &= -4.32\times10^{-4}(4\hat{x}-3\hat{y}) \\ &= \boxed{-1.73\times10^{-3}\hat{x} + 1.30\times10^{-3}\hat{y}\,\text{N}}\end{aligned}$$

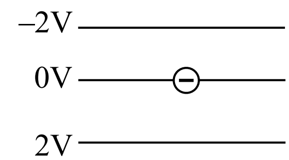
[3] **12.** __B__ A $-4\,$mC charge feels a $2\,$N force upward due to an electric field. That electric field is $\vec{E} =$

A) $500\,$N/C ↑ **B)** $500\,$N/C ↓ **C)** $8\,$mN/C ↑ **D)** $8\,$mN/C ↓

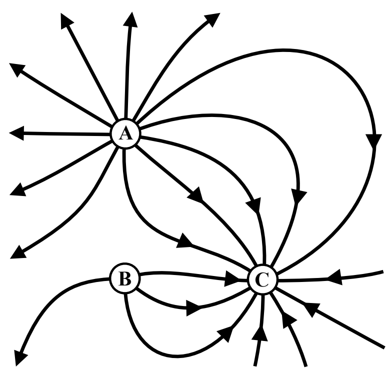


$$E = \frac{F}{q} = \frac{2\,\text{N}\uparrow}{-0.004\,\text{C}} = 500\,\text{N/C}\downarrow$$

3 **13.** D A negative charge is placed on the 0 V equipotential surface as shown. In what direction will it begin to move?
A) ← **B)** → **C)** ↑ **D)** ↓ **E)** ⊙ (out) **F)** ⊗ (in)



14. Here are the field lines created by three charges (A, B, and C):



3 (a) List the negative charge(s).

C

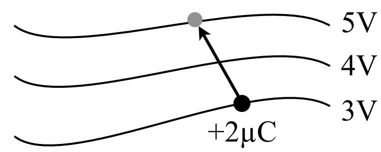
3 (b) A Which charge has the larger $|q|$, A or B?
A) A **B)** B **C)** Both charges have the same magnitude

2 (c) A The total charge of all three charges is
A) positive **B)** zero **C)** negative

15. The figure shows three equipotential surfaces, and a positive $+2\,\mu$C charge. (The charge does not create the equipotentials.)

3 (a) If I move this charge from 3 V to 5 V as shown, what is the change in the system's potential energy?

$$\Delta PE = q\Delta V = (2\,\mu\text{C})(5\,\text{V} - 3\,\text{V}) = \boxed{4\,\mu\text{J}}$$

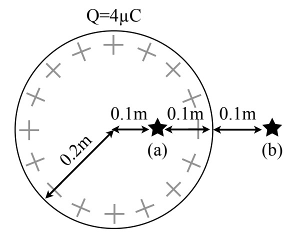


2 (b) **T** True or false: I would have to do positive work on this charge to make this move.

The potential energy rises; it has to come from somewhere.

3 (c) **B** What direction does the electric field point in this picture, roughly speaking?
A) ↑ **B)** ↓

16. Consider a spherical shell with a radius of $R = 0.2\,\text{m}$ and a total charge of $4\,\mu\text{C}$ spread evenly on its surface.



2 (a) **A** Find the electric field **inside** the sphere, 0.1 m from the surface.

A) $0\,\text{N/C}$
B) $4.0 \times 10^5\,\text{N/C} \leftarrow$ **C)** $4.0 \times 10^5\,\text{N/C} \rightarrow$
D) $9.0 \times 10^5\,\text{N/C} \leftarrow$ **E)** $9.0 \times 10^5\,\text{N/C} \rightarrow$
F) $3.6 \times 10^6\,\text{N/C} \leftarrow$ **G)** $3.6 \times 10^6\,\text{N/C} \rightarrow$

2 (b) **C** Find the electric field **outside** the sphere, 0.1 m from the surface.

A) $0\,\text{N/C}$
B) $4.0 \times 10^5\,\text{N/C} \leftarrow$ **C)** $4.0 \times 10^5\,\text{N/C} \rightarrow$
D) $9.0 \times 10^5\,\text{N/C} \leftarrow$ **E)** $9.0 \times 10^5\,\text{N/C} \rightarrow$
F) $3.6 \times 10^6\,\text{N/C} \leftarrow$ **G)** $3.6 \times 10^6\,\text{N/C} \rightarrow$

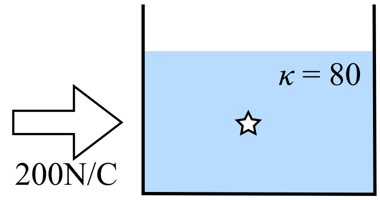
The field stays the same if I replace the sphere with a point charge at its center.

$$\vec{E} = k\frac{Q}{d^2} = (9 \times 10^9)\frac{4 \times 10^{-6}}{0.3^2}$$

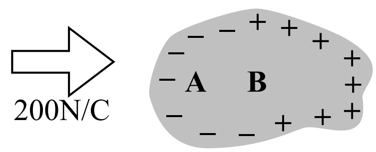
away from the sphere.

2 **17.** C ________ A cup of distilled water is placed in an electric field of 200 N/C that points to the right. Water has a dielectric constant of $\kappa = 80$. What is the net electric field at the star?

A) 2.5 N/C ← **B)** 16,000 N/C ←
C) 2.5 N/C → **D)** 16,000 N/C →



18. A metal hunk of metal is placed in an electric field of 200 N/C that points to the right. The metal polarizes, as shown, and is in electrostatic equilibrium. Points *A* and *B* are inside the metal.

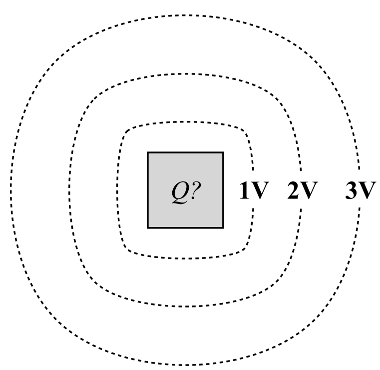


2 (a) B ________ What is the electric field at A?
A) ← **B)** zero **C)** →

2 (b) C ________ At which point is the electric potential larger?
A) A **B)** B **C)** The potential is the same at both

3 **19.** C ________ The figure shows a box with charge Q, and a series of equipotential surfaces created by it. The box's charge is

A) positive **B)** zero **C)** negative



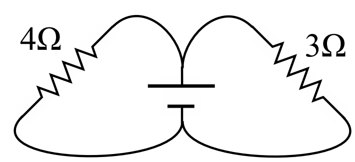
3 **20.** **E** A metal box has a capacitance of $6\,\mu$F, and is 5 V lower than the potential at infinity. What is the charge on the box?

A) $-1.2\,\mu$C **B)** $+1.2\,\mu$C **C)** $-8.3\,\mu$C **D)** $+8.3\,\mu$C **E)** $-30\,\mu$C **F)** $+30\,\mu$C

$$Q = C\Delta V = (6\,\mu\text{F})(-5\,\text{V}) = -30\,\mu\text{C}$$

3 **21.** **C** The effective resistance of these two resistors is

A) $0.14\,\Omega$ **B)** $0.58\,\Omega$ **C)** $1.71\,\Omega$ **D)** $7.00\,\Omega$

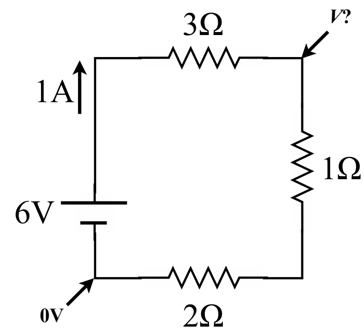


$$G_{\text{eff}} = \frac{1}{4}\mho + \frac{1}{3}\mho = 0.583\mho \implies R_{\text{eff}} = \frac{1}{G_{\text{eff}}} = 1.7\,\Omega$$

22. This circuit has a current of 1 A flowing through it.

[2] (a) **C** Which resistor releases the most power?
A) $1\,\Omega$ **B)** $2\,\Omega$ **C)** $3\,\Omega$ **D)** All the same

All resistors have the same current, so $P = I^2R$ says more resistance equals more power.



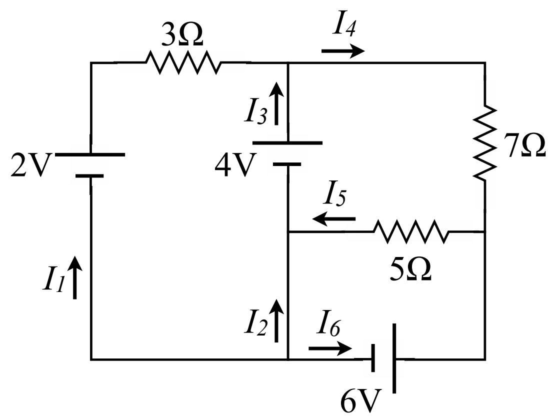
[2] (b) What is the power output by the battery?

$$P = I\Delta V = (1\,\text{A})(6\,\text{V}) = \boxed{6\,\text{W}}$$

[3] (c) If the potential at the lower-left corner of the circuit is 0 V, what is the potential V at the upper-right corner of the circuit?

$$+6 - (3\,\Omega)(1\,\text{A}) = \boxed{3\,\text{V}}$$

23. Consider the following circuit.



3 (a) **D** Which of the following is true?
A) $I_1 = I_2 + I_3$ **B)** $I_1 = I_3 + I_4$ **C)** $I_3 = I_1 + I_4$ **D)** $I_4 = I_1 + I_3$ **E)** None of the above.

3 (b) Write a loop rule involving the 4 V battery.

One of these (or there may be others)

$$4 + 3I_1 - 2 = 0$$

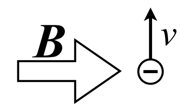
$$4 - 7I_4 - 5I_5 = 0$$

$$4 - 7I_4 - 6 = 0$$

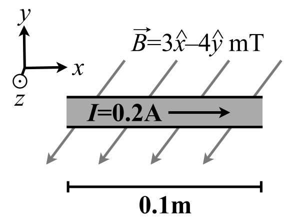
3 (c) Find I_5.

$$6 - 5I_5 = 0 \implies I_5 = \frac{6}{5} = \boxed{1.2\,\mathrm{A}}$$

3 **24.** ___**E**___ What is the direction of the force on this negative charge that is moving upward?
A) ← **B)** → **C)** ↑ **D)** ↓ **E)** ⊙ (out of page) **F)** ⊗ (into page)



3 **25.** A 0.1 m long wire carries $I = 0.2$ A in the $+\hat{x}$ direction in a magnetic field $\vec{B} = 3 \times 10^{-3}\hat{x} - 4 \times 10^{-3}\hat{y}$ T. Find the force on the wire. For partial credit, indicate the *direction* of the force.



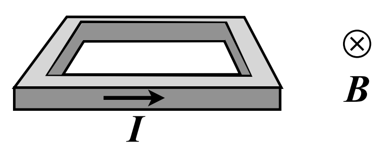
$$\vec{F} = I\vec{L} \times \vec{B}$$

$$= (0.2\,\mathrm{A})(0.1\,\mathrm{m}\hat{x}) \times (3\hat{x} - 4\hat{y}) \times 10^{-3}\,\mathrm{T}$$

$$= 0.02 \times 10^{-3}\,[3\hat{x} \times \hat{x} - 4\hat{x} \times \hat{y}]$$

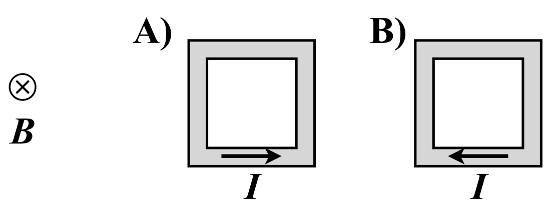
$$= 2 \times 10^{-5}\,[0 - 4\hat{z}] = \boxed{-8 \times 10^{-5}\,\hat{z}\,\mathrm{N}}$$

26. This square loop of wire is placed in a magnetic field which points into the page. Current flows through the wire as shown.

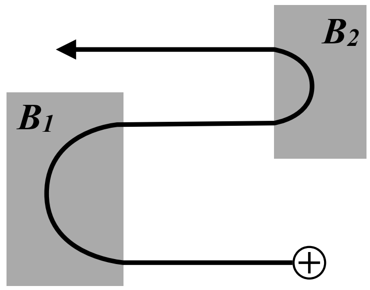


2 (a) ___**A**___ The magnetic dipole moment of the loop at the moment pictured is
A) ↑ **B)** ↓ **C)** ⊗ (in) **D)** ⊙ (out)

2 (b) ___**B**___ The loop will turn until it is oriented in which of the following directions?



27. A positive charge initially moves to the left. Two magnetic fields, B_1 and B_2, cause it to take a serpentine path as shown. The charge's speed remains constant.

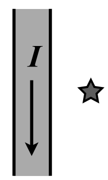


2 (a) ___B___ What direction does B_1 point?
A) into the page ⊗ **B)** out of the page ⊙

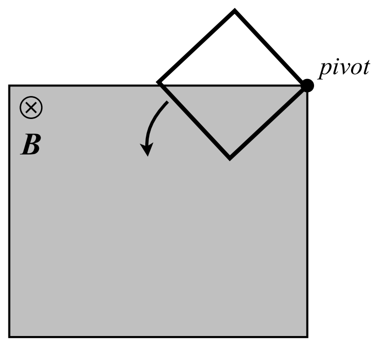
2 (b) ___A___ What direction does B_2 point?
A) into the page ⊗ **B)** out of the page ⊙

3 (c) ___B___ Which field is stronger in magnitude?
A) B_1 **B)** B_2 **C)** Both have the same strength

3 **28.** ___F___ A wire carries a current downward. The magnetic field it creates at the star points
A) ↑ **B)** ↓ **C)** ← **D)** → **E)** ⊗ (in) **F)** ⊙ (out)

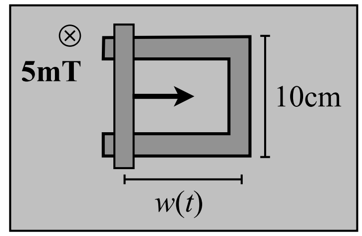


3 **29.** ___B___ A square loop of wire can pivot as shown. At this moment, the wire is swinging into a region of uniform magnetic field. Which is true?
A) A **clockwise** ↷ current is induced in the wire
B) A **counterclockwise** ↶ current is induced in the wire
C) No current is induced in the wire
For partial credit, explain your reasoning. (For example, you could give your answer to the Four Questions.)



The external flux is ⊗ and increasing, so the induced flux is ⊙.

30. A metal bar slides along a U–shaped piece of metal, forming a closed loop that current can run through. The entire device is in a magnetic field $B = 5 \times 10^{-3}\,\mathrm{T}$ which points into the field. The height of the loop is $0.1\,\mathrm{m}$ and the width of the loop is decreasing with time: $w(t) = 0.2\,\mathrm{m} - (0.005\,\mathrm{m/s})t$.



[3] (a) **A** What direction does the induced current run in the circuit?

A) Clockwise ↷ **B)** Counterclockwise ↶

[3] (b) Find the induced emf $|\mathcal{E}|$ in the wire.

The flux through the loop is $\Phi = \vec{B} \cdot \vec{A} = BA = Bhw$ and the induced emf is

$$\mathcal{E} = \frac{d\Phi}{dt} = \frac{dBhw}{dt} = Bh\frac{dw}{dt}$$

(B and h are constants with respect to time. The derivative of $\frac{dw}{dt} = -0.005\,\mathrm{m/s}$, and so

$$|\mathcal{E}| = (5\times10^{-3}\,\mathrm{T})(0.1\,\mathrm{m})(0.005\,\mathrm{m/s}) = \boxed{2.5 \times 10^{-6}\,\mathrm{V}}$$